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PHYSIOLOGICALLY ARID HABITATS AND DROUGHT RESISTANCE IN PLANTS[1]

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In the course of the investigations on the ecology of a local bog, the trend of the work has invited a closer consideration of a number of points of interest to a physiologist. The importance of these in life processes has been the occasion to offer, in the following, a statement of at least the more special cases.

In previous papers (this journal) attention has been called to the fact that the physiological effect of bog water and bog soil to a great extent plays an important primary rôle in the determination of the flora which can best succeed in bogs. It was shown that a number of cultivated plants and plants from different but neighboring habitats in the same locality fail to develop normally when grown in the bog or under laboratory conditions, and that the toxicity of the habitat appeared, therefore, to exert a marked influence in determining not only the character but also the distribution of plants within the same habitat. A difference was shown to exist between different species in their power of resistance to the toxic action of the substratum, so as to leave no doubt that some species of plants are better adapted than others to growing in soils containing relatively large amounts of these toxins. It was further shown that in the effect of a salt of calcium, and especially in the presence of a number of insoluble adsorbing bodies, these differences are much less pronounced, and that the substances tend very greatly to diminish, not only the difference between different species as to their tolerance, but also the differences in physiological aridity existing between different zones within the same habitat. With the establishment of certain definite relations between toxicity and physiological behavior of plants, it seemed desirable to study somewhat more closely the nature of the resistance in bog plants to toxicity, and consequently to physiological drought.

One of the most effective methods of dealing with the problem, and one which is particularly apropos at this time, is the study of the character and the development of drought resistance in bog plants. This should naturally be the first consideration. Too little experimental information is available in the whole field of plant responses, whether as adjustments or adaptations, and our knowledge of plant problems connected with resistance in plants to sterile soils or to unfavorable climate is particularly limited. The modifications of structure which can be attributed to the action of these and other environmental factors are well known, and may be referred to structures serving to reduce the evaporation of water from leaves. The necessity for such protection in bog plants is the greater, not on account of the fact that the vegetation is directly exposed to the drying effect of wind, to lower humidity, and to stronger light, but because roots absorb water with difficulty when it contains any considerable percentage of toxic ingredients. Unless bog plants differ from other plants in some phase of root function, the amount of transpiration must be kept low by structural modifications, that is, in order to compensate a reduced absorbing activity of the roots, the escape of water from the shoots must be correspondingly checked. It is unnecessary here to cite in detail the structural modifications in bog plants that are effective in diminishing transpiration: the general reduction in size of the leaves; the thick-walled epidermis and hypodermal tissues, reinforced by cuticle, wax, and hairs; the mucilaginous and resinous bodies found in roots and leaves; and the prevailing grasslike form are well-known characteristics. But much of the local bog vegetation exhibits little or no xerophytic structure. In some places the outermost growth which immediately borders the open water is, indeed, for the most part hygrophile. It is dominated, in part, by *Typha latifolia*, forming sometimes a nearly pure association. *Sagittaria latifolia*, *Pontederia cordata*, *Peltandra virginica*, *Decodon verticillatus*, *Polygonum hydropiperoides*, and others are ordinarily abundant with Typha. The xerophytic quality is least marked in this vegetation. Differences such as these must arise strictly from the edaphic causes, which seem to set a natural and inevitable limit to what may be accomplished through invasion. There is but one important point of difference between the environment of the bordering vegetation and that of the bog plants occurring more centrally on the island, and that is the relative absence of toxic ingredients in the water and in the upper limits of the substratum. The transpiration quantity of such hydrophytic plants is correspondingly less when grown in bog water from the central habitat. The low rate of transpiration can be increased again with the addition of adsorbents, or with the dilution of the bog water to a point no longer fatal in its effects. The peat substratum of the border zone permits, on that account, a dense luxuriant growth of hydrophytes, and neither a smaller percentage of free oxygen in the water, nor the absence of a mineral soil, nor the incoherency of the substratum affords precarious conditions for growth.

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[1] Contribution from the Botanical Laboratory of Ohio State University, 55.

How much of the salts dissolved in the lake water is retained by absorption in the humus soils along the margin of the bog has not been determined. There is usually a slight difference between the total mineral content of bog water and that of the lake water adjoining. The figures obtained, however, are not high. The osmotic pressure and the acidity have been found to be the same for both habitats. The stress laid by various authors upon the relation of these two factors to plant societies in bogs, in so far at least as this region is concerned, will not hold. They are not the factors in the selection and distribution of species.

Water culture experiments are here considered as giving a relatively normal indication of conditions obtained in the bog, since the bog island itself is merely a water culture on a larger scale, with the mineral soil at a depth of more than 10^m from the surface vegetation. In the bog habitat of the island, however, the ratio between the amounts of water absorbed and transpired is never constant. It varies most during the growing season, and yet it must be always more than unity, if the plants are to survive the occasional periods of extreme physiological drought during the summer and autumn months. This is evident in the scattered small trees of *Acer rubrum*, *Rhus vernix*, and in *Cephalanthus occidentalis*, *Osmunda cinnamomea*, and other plants from the adjoining relatively forested maple-alder zone. The stunted growth of these plants, their numerous dead branches, and ragged crown of foliage exhibit to a marked degree the physiological action of the substratum. The resistance offered by the invading mesophytic vegetation is, indeed, but slightly effectual. The relative power in the bog plants for absorbing or rejecting the various injurious constituents of bog water and bog soil is here the controlling factor. This regulatory compensation within certain limits, therefore, is of utmost importance in these species, for we have here an instance of the fact that while the presence of structural modifications is generally regarded as a circumstance in favor of a bog vegetation, the most noteworthy characteristic is the ability to neutralize the injurious action of the substratum. In so far as the adjustments arise through resistance to toxicity and consequent drought, one is painfully aware that neither the nature of the drought resistance, its origin, its specific governing factors, nor the specific type of resistance involved in the adaptation of plants to toxic bog conditions is known.

Another matter of fundamental importance is the degree in which this drought resistance in physiologically arid habitats varies, and the extent to which it is inherited. That activities are not constant but variable in degree and in kind, and that functional characteristics in plants are transmitted as effectively as habit of growth, form, flower, and seed, is generally admitted. The conditions of life in bogs are always active in stimulating or depressing normal functions, and they are not without effect upon their degree and character as well. The disturbing effect of adverse conditions, if not too severe, may be gradually overcome through variations in the degree of activity. Often the unfavorable external conditions are conducive to the development of a new *place-function*, and the immunization may extend to the point that would be fatal at the outset. Thus plants reared in a gradually intensified toxic solution have reached a power of resistance above that of the organisms under normal conditions. It seems possible to raise forms in which the special resistant power becomes a permanent hereditary character. Phenomena such as these are remarkable for what they suggest rather than for conclusions that can be positively drawn, since the degree of resistance which plants acquire by external or other influences to poisons and drought, or to other adverse conditions of life, may be one in which the activities are modified, resulting, as has been stated, in a new place-function, or one in which the plants succeed in resisting the changed conditions through greater elasticity in functions. A knowledge of the limits of functional variation within species, therefore, is very essential. Deviations in the very functioning of the process, and in transmission as well, cannot but be fruitful in a greater efficiency of responses in plants, and without doubt these are the differences that go far toward constituting the essential difference between relative power of endurance and resistance against drought, disease, or abnormal conditions in any plant. The circumstances under which bog plants can function unaltered, either in character or degree, and the limits beyond which such functions must cease or become altered, are questions of special significance in physiological ecology. They throw no little light upon the nature of tolerance and drought resistance, a topic upon .which information is sorely needed if we are to regard functions no less important in the light of development and heredity than form or structural organization.

Of still greater consequence is the study of such limiting factors of soil and climate as operate to preserve adapted forms, or eliminate species in which the responses fail to secure better adaptation to the factors provided by a local region. The presence and fitness of bog plants and of invading hydrophytes and mesophytes resistant to physiological drought seem to be due mainly to more efficient responses to edaphic conditions. In most cases, at least, drought resistance involves a specific reaction on the part of the plant to more than one factor of the physical and biotic environment, the ratio between the factors in the process being more significant than the structural modifications or the regulatory compensation which may be possible within the plants. The reaction may be in part one of structural differences, and in part one of endurance. The evidence cited in the work published, and experiments now in progress indicate that drought resistance in physiologically arid habitats is due to a specific protective functional root activity. It is fundamentally a chemical reaction, but one too complex to solve by ordinary methods of chemistry. The delicacy of the reaction may be better understood if we recall the fact that it is adjusted to meet a specific limiting condition. Whether the toxic action of bog water and bog soil is determined by the action of one constituent, or by the combined action of several, needs more detailed study. As has been noted elsewhere, the toxicity of any bog soil is but a function of the number of the conditions of its development, and of the physiological efficiency of these factors.

Recent work of an experimental nature with cultures of isolated bog bacteria has shown that the injurious products of the bacterial bog flora accumulating in definite layers of the peat substratum are the leading factor to be considered in the physiological aridity of the local study. The observation was made that a sample of bog water in a well-corked glass jar, when kept in the dark at 20–25° C., soon shows the formation of methane and other gases, and that in a few weeks a thin surface layer becomes noticeable made of up bacteria imbedded in a matrix. Exclusion of air prevents further growth of aerobs, for in flasks with narrow necks and closed with a cotton plug a surface growth is never evident. The breaking down of organic matter by bacteria seems to involve, therefore, not only the growth and multiplication of the agents of decomposition, but also an accumulation of by-products which soon decreases the rapidity of aerobic bacterial action. Facts to justify the position as to the presence of a constituent that imparts an antiseptic action to bog water and bog soil are still lacking, but there is sufficient experimental evidence to justify the statement that the bacterial flora has the greater share, not only in the formation of these toxins, but also in the slow and partial decay of bog and swamp plants, that is, in the formation and preservation of peat. An attempt has been made to study the physiological reaction of the products formed from the activity of single isolated species, as well as the effects of the residual products due to mixtures of bog bacteria. Without going into too much detail it is sufficient to point out here the following:

From a fresh sample of bog water and bog soil dilution cultures were prepared. The isolation of the various species was continued upon peat-agar plates, and later in test tubes containing a beef-broth-agar medium, until from the bacterial colonies which appeared upon them, pure cultures were obtained. About 35 different species of bacteria have thus far been isolated. The organisms belong for the most part to the aerobs. Of the bacteria thus isolated, 21 were tested for their toxin-producing power upon a sterilized solution of bog water and peat. A number of flasks of a liter capacity containing the sterilized solution were then inoculated with the respective pure cultures. Several flasks were left sterile to serve as controls, while others were inoculated with a mixture of the various species and with the bacteria found in 1^{cc} of fresh bog water. An additional test condition was arranged at the same time from the normal untreated bog water. All flasks were placed in an incubator for a period varying from two to four or six weeks, and at such times were then brought to the laboratory. All physiological tests were made in duplicate series, and the greatest caution was observed to reduce the dangers of contamination during the preparation of the cultures. Wheat seedlings germinated in sterilized quartz and carefully washed in distilled water were used as indicators. They were transplanted to half-liter "Mason" jars in a manner as described in previous papers.

From the data at hand the following have been selected to illustrate the variation in virulency of bacterial products. Using the transpiration of the controls as a basis, and representing it as 100, the different bacterial cultures have values in the order as indicated in the last two columns of the tables below.

These figures show conclusively that in all cases the bacteria are responsible for the proportionally diminished transpiration and growth of the wheat plants. In all cultures the transpiration values lie below that of the control, varying from 20 to 52 per cent. The evidence derived from the duplicate series is omitted in tables II and III, showing as it does results closely parallel.

More recent experiments with pure and mixed cultures of bog bacteria confirm the earlier experiments as to the ability of these organisms to increase the amount of toxins present in the peat substratum. These results are significant in that they demonstrate the active participation of microorganisms in bog habitats, a fact contrary to the position taken by FRÜH and SCHRÖTER, who regard the bacterial influence as very small. To what extent the tables suggest the possibility that bacterial diagnosis when correlated with physiological criteria may determine the crop-producing power of different agricultural soils need not be discussed here.

Chemically peat is made up of substances which are commonly classified among the dehydration products of the carbohydrates. The analyses which have been made agree in showing that the phosphoric acid content of peat soils is high and partially in an available condition for plant use. In potassium content they are deficient; potassium salts are generally added in an alkaline form in order to produce crops. In nitrogenous materials peat soils are unusually rich, but the nitrogen remains bound up in organic compounds unavailable for the growing cultivated plants. In order to determine the ability of the microorganisms to convert soluble proteids into amido-acids and allied products of the disintegration of proteids,

TABLE I

TRANSPIRATION DATA FOR SOLUTIONS INOCULATED WITH PURE CULTURES OF BOG BACTERIA

SERIES III	BACTERIA	TRANSPIRATION IN GRAMS				COMPARATIVE TRANSPIRATION	PERCENTAGE OF DECREASE
		5th day	10th day	15th day	Total		
	Control	9.33	42.92	66.85	119.10	100	0
	B. 20	8.85	41.30	44.06	94.21	79.10	20.90
	B. 22	8.30	38.15	42.90	89.35	75.02	24.98
	B. 7	8.55	31.80	42.80	83.15	69.81	30.19
	C. 3	7.15	30.90	43.95	82.00	68.85	31.15
	C. 4	7.60	29.70	44.40	81.70	68.59	31.41
Duplicate series....	Control	8.80	44.50	66.83	120.13	100	0
	B. 20	8.40	34.25	45.98	88.63	73.77	26.23
	B. 22	7.05	35.40	46.10	88.55	73.71	26.29
	B. 7	8.15	34.45	42.21	84.81	70.59	29.41
	C. 3	8.10	30.90	44.25	83.25	69.30	30.70
	C. 4	8.40	31.15	41.65	81.20	67.59	32.41
Atmometer..		102 gr.	136 gr.	125 gr.			

TABLE II

TRANSPIRATION DATA FOR SOLUTIONS INOCULATED WITH PURE CULTURES OF BOG BACTERIA

SERIES VII	BACTERIA	TRANSPIRATION IN GRAMS				COMPARATIVE TRANSPIRATION	PERCENTAGE OF DECREASE
		5th day	10th day	15th day	Total		
	Control	17.65	36.20	36.60	90.45	100	0
	Bog water	7.65	11.30	8.90	27.85	30.79	69.21
	B. 25	18.15	29.30	26.85	74.30	82.14	17.86
	Bg. w. 1^{cc}	18.27	30.15	25.70	74.12	81.94	18.06
	B. 13	15.72	24.65	30.85	71.22	78.74	21.26
	B. 2	17.45	29.05	24.30	70.80	78.27	21.73
	B. 1	16.60	28.95	24.85	70.40	77.83	22.17
	B. 27	12.60	24.90	22.80	60.50	66.66	33.34
	B. 6	14.00	25.40	20.80	60.20	66.55	33.45
	B. 4	14.95	23.80	20.45	59.20	65.46	34.54
	B. 29	11.60	15.55	15.85	43.00	47.54	52.46
Atmometer..		114 gr.	117 gr.	102 gr.			

enough pepton was added to sterilized solutions to make an equivalent of a 1 per cent pepton culture. After sterilization the solutions were inoculated with the bacteria indicated in table III. The cultures were tested physiologically at the end of a two-week incubation period. Since the danger of contamination in pepton cultures becomes increasingly greater, the transpiration figures for only the first five days are tabulated. The wheat plants had grown in each experiment for three days when they were photographed.

TABLE III

TRANSPIRATION DATA FOR 1 PER CENT PEPTON CULTURE SOLUTIONS, INOCULATED WITH BOG BACTERIA

Series IX	No.	Bacteria	Transp. (5th day), in grams	Comparative transpiration	Percentage of decrease
	6	Control	17.65	100	0
	7	Pepton check	7.00	39.65	60.35
	13	B. 13	4.85	27.47	72.53
	14	B. 25	2.70	15.30	84.70
	11	B. 2	2.30	13.03	86.97
	12	B. 4	2.40	13.60	86.40
	15	Bg. w. 1^{cc}	1.87	10.60	89.40

A brief inspection of the figures suffices to show that transpiration, growth, green and dry weight of plants are in this case proportionally reduced. The mixed culture solution (Bg. w. 1^{cc}) in which the percentage decrease in transpiration is as low as 90, seems to show that it is the function of some of the bacterial organisms to do the initial work of rendering soluble the protein compounds in a peat substratum. The process of denitrification is carried on up to a point where the products become further decomposed by other organisms. A whole series of bacteria, therefore, seems to be involved, to which are due the residual products, the sum of which in part constitutes the toxicity of the habitat encountered on Cranberry Island, the formation of methane gas, and the reactions which form the basis of the process of humification.

At the end of the experiment a chemical examination of these culture solutions indicated the presence of indol, ammonia, and various non-volatile products in various proportions. A marked difference was noted in the ability of the different species of bacteria to produce indol and ammonia. The highest quantity of ammonia was produced by B. 13; the least amount was recorded for Bg. w. 1^{cc}, the culture solution, it will be remembered, which consisted of a mixture of the bacteria found in 1^{cc} of fresh bog water. None of these products were found in the control (sterilized bog water and peat). It is also to be noted that in the various pure bacterial cultures neither the organic acids nor the ammonia underwent a further change; in the mixed cultures, however, the decomposition continued, the amido-acids being formed to ammonia and to compounds of the fatty acid series. The extent to which the latter substances may be still further disintegrated to carbon dioxid, hydrogen, and methane is now being determined. Thus far the isolation of bacteria involved in the decomposition of carbohydrates has not been successful. Certain microorganisms have been found to possess the ability to dissolve cellulose (filter paper) in the presence of air. To what extent these forms and the anaerobs play a rôle in the relation of deleterious products in the soils and the cultivation of crops is still uncertain. In a previous paper (BOT. GAZETTE **47**:400. 1909) the writer has reported that the poisonous matter injurious to plant growth is present in the agricultural soils used as filters for bog water. The retardation seen in the contaminated soils lacked the corresponding control average in dry weight of plants to an amount of 18 per cent, 3 per cent, and 36 per cent, for sand, clay, and humus soil respectively. It was further shown that the absorption and retention capacity of soils for toxins became generally higher the greater the content in humus.

In concluding this part of the discussion it is well to note the extent to which the results show clearly that, in the laboratory cultures at least, the retardation in growth of wheat plants is not caused by physical or chemical conditions, but through the direct activity of the bacterial flora upon the peat substratum.

It has long been suspected that a reciprocal relation exists between groups of soil bacteria and the plants growing upon the soil. Various writers have been able to point out that marked differences in the productive power of different soils followed the growth of wild plants, and that these differences persist for some time. It is generally concluded, therefore, that the injury caused to cultivated plants by weeds or previous crops is due to influences on the bacterial life in the soil, and in a direction unfavorable to succeeding agricultural crops. No doubt, the "exhaustion" of soils which is frequently met with, and which cannot always be attributed to the removal of plant nutrients is, in part, an allied phenomenon. It cannot remain a matter of indifference to physiological ecologists whether a strong, intimate, and controlling relation exists between soil bacteria and surface flora, and how the bacterial organisms affect the character, and the association and succession of plants. At best very little is known of this phase of the process, and of the reactions and effects of the bacterial products upon plant life. It would be idle, also, to expect that the bacteriological data in themselves are sufficient for a clear interpretation of toxicity and drought relations, or of sterility of soils. If attempted, the interpretation would be, indeed, one-sided; there is a coordination of factors, each and all of which exert a relatively marked influence. Temperature, water, and air conditions in the soil, as well as the physical and chemical character of it, and the surface flora play an important rôle in determining the character of the bacterial flora, and therefore also the character of the chemical products formed. The bacteriological-chemical, as well as the physiological method, deserves on that account a closer consideration. The determination of the transformation products in various media inoculated with bog bacteria should possess an exactness and a reliability that should make it suitable for the solution not only of agricultural but of ecological problems as well. It is hardly necessary to go into further detail. It is only too clear that the need for new investigations is pressing, and that especially new points of view and new lines of research are imperatively required.

From the point of view of limiting environmental factors, structural differences do not seem to play much part in enabling plants to exist in bog conditions, for the bog xerophytes, as CLEMENTS contends, are dry-land plants, which have retained the distinguishing marks of the original habitat. They are characterized by their ability to adjust themselves to changed conditions without undergoing a corresponding change of structure. Indeed, drought resistance too often results from exceptional vigor and power of endurance rather than from persistence of ancestral or new variant characters. Injury and death result only when the condition surpasses the maximal limit. The inspection of even a few experiments with these distinctions in mind is likely to convince anyone at all familiar with such observations, that the best functioning plants, rather than the general average, represent the proper test of the possibilities of the species under the given conditions. Adjustment to local conditions is in these cases a more striking phenomenon than acclimatization, and it is to be looked upon as quite apart from structural divergence. While conclusive experiments may not as yet be admissible, the data at hand make it highly probable that the resistant forms among the hydrophytes and mesophytes in the mixed bog formations arise through gradual rather than sudden development, and that functional variation is the essential criterion. One of the results of introducing agricultural varieties into bog conditions is the comparative lack of uniformity in type, variants departing in both directions from the normal, and different varieties responding in different ways to the same conditions. Planting a species in a new place is in the nature of a test of the stability of its characters under the new conditions. Some changes result in a new place-function, but many of the changes of character that occur do not serve as responses, but result in wide individual differences and deterioration from loss or from disturbance of functional adjustments to previous established conditions. To inquire, therefore, into the nature of the adjustments of disturbed characters is to gain an indication, not so much of the many forms that the plant is able to assume, as especially the possibilities of the restoration of a balanced expression of functions which thus allow the most advantageous changes again to be established. An adapted and resistant form, if segregated through continued selection, may thus prove the basis of valuable data in the study of plasticity and fixity of organs or of type. It may prove doubtful whether the substratum solution is of a nature to bring out the greatest variation in form and in resistance. Experiments will have to be performed on a larger number of plants of widely different relationship before definite conclusions can be reached. Much economic value would attach to an extension of these experiments by using a salt or a mixture of more than one salt to ascertain a physiologically balanced solution for other kinds of plants. As has been stated above, there is an indication that the toxicity of the habitat is not the same for all agricultural plants and forest trees, and that, hence, from the point of view of the economic importance of these results, it may be found that a certain species, that is, that one crop, is better adapted than another to withstand the effects of this type of soil. Certainly an opportunity exists through such studies for an increase in the utility of these soils, and for a better understanding as to the character and the nature of functional responses of plants adapted to them.

Leaving out of consideration for the present studies of plants which deal with functional variability and with selection, we may speak with much more confidence of the fact which environmental factors exert upon diversity of function. This effect can be much more readily studied and shows itself much more conspicuously. In fact, a knowledge of drought resistance in plants within a physiologically arid habitat will be gained mainly by securing data as to the relation of plants to environmental factors. It is quite generally agreed that transpiration is one of the most important criteria in physiological ecology. Transpiration data are more conveniently obtained, if not more serviceable in this respect, than data on respiration differences or on green and dry weight of plants. Aside from the physiological responses of roots and leaves, the most significant physical conditions which more than others directly affect transpiration in plants, are the supply of available water to the roots, and the evaporation power of the air. On account of this distinctive feature, the problem separates itself into two phases, each of which must be considered by itself. The one relates to the influence of the varying edaphic conditions, the other to the effects of climate. The two are quite different, and each is of relatively great importance. Taken by themselves neither should be unduly drawn upon in the interpretation of drought or other resistance. The futility of the point of view which disregards all but one or two influences is seen clearly enough in the laboratory. But the inadequacy of such proposals is still more apparent when we attempt field work.

A consideration of the physiological causes underlying the conditions stated has led to the conclusion that for the local study extensive investigations in the heat requirements of bog plants and the location of their minimum temperature below which growth ceases (MERRIAM, also SWINGLE) do not have the importance which must be ascribed to temperature as a limiting factor for regions widely separated geographically. Except for the fact that growth in local bogs begins earlier in spring and continues later in autumn than in bogs of more northern regions, the data at hand on the differences between air and soil temperatures and on the total temperature exposure of plants covering a period of three years, show that low substratum temperatures, i.e., winter temperatures below 0° C. at the one-foot level (30^{cm}) and below $+3°$ C. at the 5-foot level (1.5^{m}), do not exist here, and hence play no part in bog structure or bog development. The more detailed account of this and other phases of the study appears elsewhere. The values of both heat-conductivity and heat-diffusion are in general lower in peat than in soils or in water, and hence prevent a rapid loss of temperature in the peat strata below the surface of vegetation. A persistence of the winter cold and ice through the summer months has not been observed in this region. Contrary, therefore, to the accepted interpretation, it is found that the imperfect decomposition of bog plants is not dependent upon supposedly low temperatures. One can readily understand that if any influence does exist the process of peat formation and preservation must be due to the presence of bog toxins and their antiseptic properties.

LIVINGSTON has shown that the evaporating power of the air furnishes an extremely valuable criterion for the differentiation between great centers of plant distribution, and also for the differentiation of certain habitats and the succession of plant societies. In connection with the problem of the transpiration values of bog plants, atmometer readings were obtained from the two stations on the bog island during the past year. A third instrument was established on the campus near the University Observatory, in an open place with an exposure to wind and sunlight similar to that in the central station on the bog. The readings of the instrument on the campus were taken three times daily, in connection with the climatological observations called for by the U. S. Weather Bureau Service. The data collected on the evaporating power of the air in the bog habitat, if compared with the evaporation rate on the campus of the University, show that the evaporating power of the air in bogs is not an important limiting factor in controlling bog vegetation, or determining the character of it. It is on the University campus that the greatest rate of evaporation was constantly recorded. The differences in the rate of evaporation between the campus and the central station on the bog island varied from 16.6 per cent to 50.4 per cent—a relative rate of evaporation at times more than twice the rate observed in the bog habitat. This relation seemed wholly unexpected and very surprising at first, for the campus area on the basis of its vegetation cannot be considered xerophytic. The general indications, therefore, point to the conclusion that at Buckeye Lake the evaporation from the water surface and from the vegetation produces a vapor blanket. The action of this invisible vapor blanket influences to a great extent the rate of transpiration of bog plants, for it conserves the moisture that would otherwise be lost by evaporation. The character of the flora and the structural conditions of bog plants, therefore, cannot be ascribed to a greater evaporating power of the air, nor to alterations in temperature conditions as has been stated so frequently. The weight of evidence from this and other investigations is again decidedly in favor of the conclusion that the real determining factor in the bog habitat is the ratio of the possible rate of water absorption to the rate of transpiration, and that the toxicity of the bog habitat has a primary rôle in bringing about bog conditions.

The extent of incontrovertible facts is still scanty. Only of late has the question of the physiological aridity of a bog habitat been removed from opinion, scientific and unscientific, to the field of experiment; and further experiments will be necessary to set clear the many complicated questions still connected with this inquiry.

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